SUITABILITY OF THE PERPENDICULAR VEGETATION (PD54) INDEX IN THE AREAS IN WHICH BIOLOGICAL SOIL CRUSTS ARE COMMON

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ABSTRACT: Biological Soil Crusts (BSC) are distributed across three quarters of Australian's land. Previous remotely-sensed studies, which were applied to areas in which BSC occur, either neglected BSC all together or considered BSC species in one group and did this when they were in a dry state. Previous studies have reported that there is a considerable similarity between the spectra of BSC and dry bare soil thus leading to potential misinterpretation. The Perpendicular Vegetation Index (commonly called PD54) was developed in the areas in which BSC were not common. However, some studies have employed this index in the areas in which BSC are common. This study utilized ground-level spectral measurements to synthesize Landsat Thematic Mapper (TM) imagery and examined the BSC effects on this index. Results showed that neither individual BSC with background soil, nor 'BSC pattern spectra' affect the vegetation and soil lines. This applies when the percentage cover of BSC varies from 1.69% to 36.99%. Thus, the use of PD54 in the application of grazing gradient analysis can be misleading as the results are insensitive to BSC presence.

1. INTRODUCTION

BSC consisting of non-vascular photosynthetic ground flora, where are well developed on the soil surface in the interspaces of open shrubland, grassland and woodland communities of arid, semi-arid and arctic ecosystems (Belnap et al. 2001). The percentage cover of BSC on these areas is as high as 0 to 100% (West 1991). Although, there is some studies, particularly for spectral characterization using both field and laboratory analysis (Karnieli and Tsoar 1995; Chen et al. 2005), there is little examinations of BSC effects on a remotely sensed approach(s) in Australia (Lewis et al. 2001; O'Neill, 1994]. Conducted studies in outside of Australia have claimed that the spectra of dry BSC are similar to that of bare soil. One of the employed indices is the PD54 and it is considered as a robust and reliable index for rangeland cover estimation in Australia. This study aimed to take BSC into account for ground-level spectral modeling to examine the sensitivity of the PD54 on the areas in which BSC are common.

2. THE PERPENDICULAR VEGETATION INDEX BY CONSIDERING GRAZING GRADIANT CONCEPT

In arid rangelands where soil reflectance is bright in all wavebands, vegetation points would conceivably occur below this soil line as vegetation reflectance is lower than bare ground reflectance. The soil and vegetation lines (Figure 1) define a two-dimensional spectral construct for each of the paired reflectances (Gitelson et al. 2002). The PD54 is based on the perpendicular distance of vegetation and soil lines in the data space of band 5 versus band 4 of Landsat MultiSpectral Scanner (MSS) (Figure 1) or band 3 versus band 2 of TM imagery and is now commonly used for rangeland monitoring in Australia (Bastin et al. 1993; Cameron and Lewis 1996; Pickup et al. 1994). The upper spectral line is presents the soil line and the lower spectral line correspond to a vegetation line (Figure 1) and represents the maximum amount of cover present in the image. The main concept in these indices is the measuring orthogonal or perpendicular difference between vegetation variables in relation to a defined soil line. It is used within a grazing gradient framework to detect response of vegetation cover to rainfall in wet and dry periods by site comparison (Pickup et al. 1993; Pickup et al. 1994), and is thought to closely relate to the percentage cover in a wide range of arid region vegetation types.

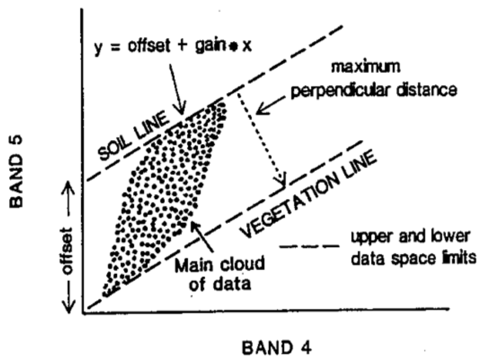

Figure 1. Basis of the PD54 vegetation index in MSS data space, after Pickup et al. (1993)

3. MATERIALS AND METHODS

3.1 STUDY AREA

This study was conducted at Middleback Field Centre (MFC), in the pastoral region of the South Australian chenopod shrubland, approximately 400 km north-west of Adelaide (137º 15'E & 32º 50' S).

3.2 SPECTRA COLLECTION

Collected spectral samples for each object are presented in Table 1. Overall 13 data series were considered to test the sensitivity of the PD54 on the area in which BSC occur. Spectral sampling was conducted for different objects (Table 1) using UniSpec spectrometer (PP Systems, 1999) in natural environment. Hemispherical reflectance of the visible and NIR (350 to 1100 nm) wavelength regions of the EMR with 3.3 nm resolution were made by this spectrometer at a Instantaneous Field Of View (IFOV) of a foreoptic the 42 degree. Taking into account the precautions such as clear atmosphere for spectral sampling, peak sunshine hours of 11.00 am to 3.00 pm, viewing geometry, the original structure of the vascular plants and BSC, well illuminated area close to the collection site that have been described by literature (Milton, 1987). Spectra were recorded in radiance mode (as opposed to reflectance) at an average of 10 to 20 scans in order to minimize instrument and natural variability noises. Radiance measurements in the visible and NIR regions were collected to maximize the signal-to-noise ratio of each measurement. Immediately before acquisition, incident radiation on the object was observed by measuring the up welling radiance from a dark current and from a Spectralon white reflectance panel (PP Systems, 1999). In post-processing the collected radiances were divided by the Spectralon panel radiance spectra to determine object reflectance (as a percentage of incidents light).

Table 1. Main land covers and BSC groups with the number of spectral samples for each group which were used in this study for PD54 (PD32) characterizations

Land covers			**Dry dataset (spectra), n =**
Bare soil			108
Stone			40
Litter			41
Shadow (bare soil under dense and sparse canopy)			27
Photosynthetic components	Vascular plants	Perennials	273
		Annuals	14
	BSC groups	Black Common Lichens (BCL)	77
		Black Common Moss (BCM)	51
		Scaly Lichens	71
		Leafy Lichens	71
		Crusty Lichens	46
		Tall Mosses	46
BSC patterns			27

For shadow data there was very high variation from under a plant, such as *Acacia* spp. with sparse canopy to the other species such as *Maireana* spp. with dense canopy. Shadow spectral data under objects of different plants were collected.

The pattern spectra / plot-based spectra with background soil were also sampled by a 3 degree (IFOV) foreoptic. For site or plot selection some criteria such as priority or importance of BSC groups and total cover of them were considered. According to the results of the classification of BSC groups, black BSC components (black lichens + black mosses) are covering more than 82% of the study sites (Ghorbani et al. 2006). Moreover, mean percentage cover of BSC was <1.69% in degraded sites to 36.99% in undegraded conditions (Ghorbani et al. 2006). Furthermore from the ground-based BSC cover analysis, it was concluded that, the potential cover of BSC is about 30 to 45% in intact or less degraded conditions (Ghorbani et al. 2006), thus spectra of less degraded conditions with at least 30% BSC cover were considered for BSC pattern spectra versus bare ground spectra. These plots were selected to have a percentage cover of black components (lichens + mosses) of more than 80% of total BSC cover. The ground coverage corresponding to an IFOV of 3º, from 50 cm distance, was less than 10 cm in diameter, so spectral data were collected inside a defined 50 × 50 cm plots.

Due to the presence of several noisy channels, the data were cropped to a range of 430–900 nm. After this data sub-setting, the spectra were partitioned into two sets comprising bands 2 (520 - 600 nm) and 3 (630 - 690 nm) of TM imagery.

4. RESULTS

Figures 2 (a to f) show BSC spectra versus other land covers in the simulated data space of TM band 3 versus band 2. As can be seen from Figure 2a, Black Common Lichens (BCL) do not overlap with bare soil. Although BCL overlap with vascular plants, there is distinct distance between the vegetation line and their patterns. This group has also overlap with litter and shadow data which is may create a source of misclassifications. The second major group is Black Common Mosses (BCM). It exhibits a distinct pattern from bare soil and does not affect the soil line (Figure 2b). It has overlap with vascular plants, but distinct distance from the vegetation line. It has strong overlap with shadow, litter and stone data. Scaly Lichens have very little overlap with soil spectra, but a distinct pattern from the soil line (Figure 2c). Scaly Lichens also overlap with vascular plant spectra, but have a distinct pattern from the vegetation line. Scaly Lichens overlap with stone, and particularly with litter data. This group has no overlap with shadow data. Leafy Lichens (Figure 2d) have no overlap with soil data, but very high overlap with vascular plants spectra. There is a distinct distance between the vegetation line and the pattern of Leafy Lichens, but it seems that this is the only BSC group that may affect the vegetation line.

They have no overlap with shadow data, and little overlap with stone and litter data. Crusty Lichens (Figure 2e) have distinct patterns from soil with no effect on the soil line, but strong overlap with vascular plants. In spite of this overlapping, there is a distinct distance between the vegetation line and Crusty Lichens. They have no overlap with shadow data, but a small overlap with stone and litter data. Tall Mosses (Figure 2f) have a distinct pattern from the soil spectra and no effect on the soil line. They overlap with vascular plants spectra, but have no effect on the vegetation line. Tall Mosses have very high overlap with shadow and litter data but very low overlap with stone data. Finally, 'BSC pattern spectra' (Figure 2g) show mixed results but with data close to the soil pattern rather than the BSC pattern. It seems that soil background affected the spectral data, and 'BSC pattern spectra' are more similar to the bare soil, BCL and mosses.

Overall, there is little overlap between total BSC components and bare soil or stone spectra except "BSC pattern spectra", but considerable overlapping with perennial plants (woody + herbage) spectra. An important point from these graphs is that BSC components do not affect the position and orientation of the soil and vegetation lines. It means almost all of the 389 BSC spectral samples are plotted between the soil and vegetation lines. More importantly, two main super-groups of BSC including BCL and BCM have data space close to the soil data, which suggest they do not affect the vegetation or soil lines. There are mixed patterns among the litter, shadow and BSC group data.

5. DISSCUSSION AND CONCLUSION

PD54 is important because it is widely used for rangeland monitoring and is concluded as the most suitable index for the Australian arid rangeland (Bastin et al. 1993; Pickup et al. 1993; Pickup et al. 1994) and it is accepted one of the reliable methods in long-term rangeland monitoring program on the winter-dominated rangelands such as South Australia. According to the ecological benefits of BSC in rangeland ecosystems, they cannot be neglected in the evaluation of rangeland change detection. Cameron and Lewis (1996) claimed that they have considered BSC in data collection for the PD54 analysis and ground-truthing. Grazing gradient patterns as 'normal', 'inverse', 'composite' and 'no gradient' (Bastin et al. 1993) are strongly related to the BSC cover (Ghorbani et al. 2006). The grazing gradient method is based on the defining of soil and vegetation lines and measurement of the perpendicular distance between these two lines on the data space of band 5 versus band 4 of MSS data by comparison of dry versus wet images (Bastin et al. 1993; Pickup et al. 1994). Our results for a rangeland area with the dominance of *Maireana* spp.,

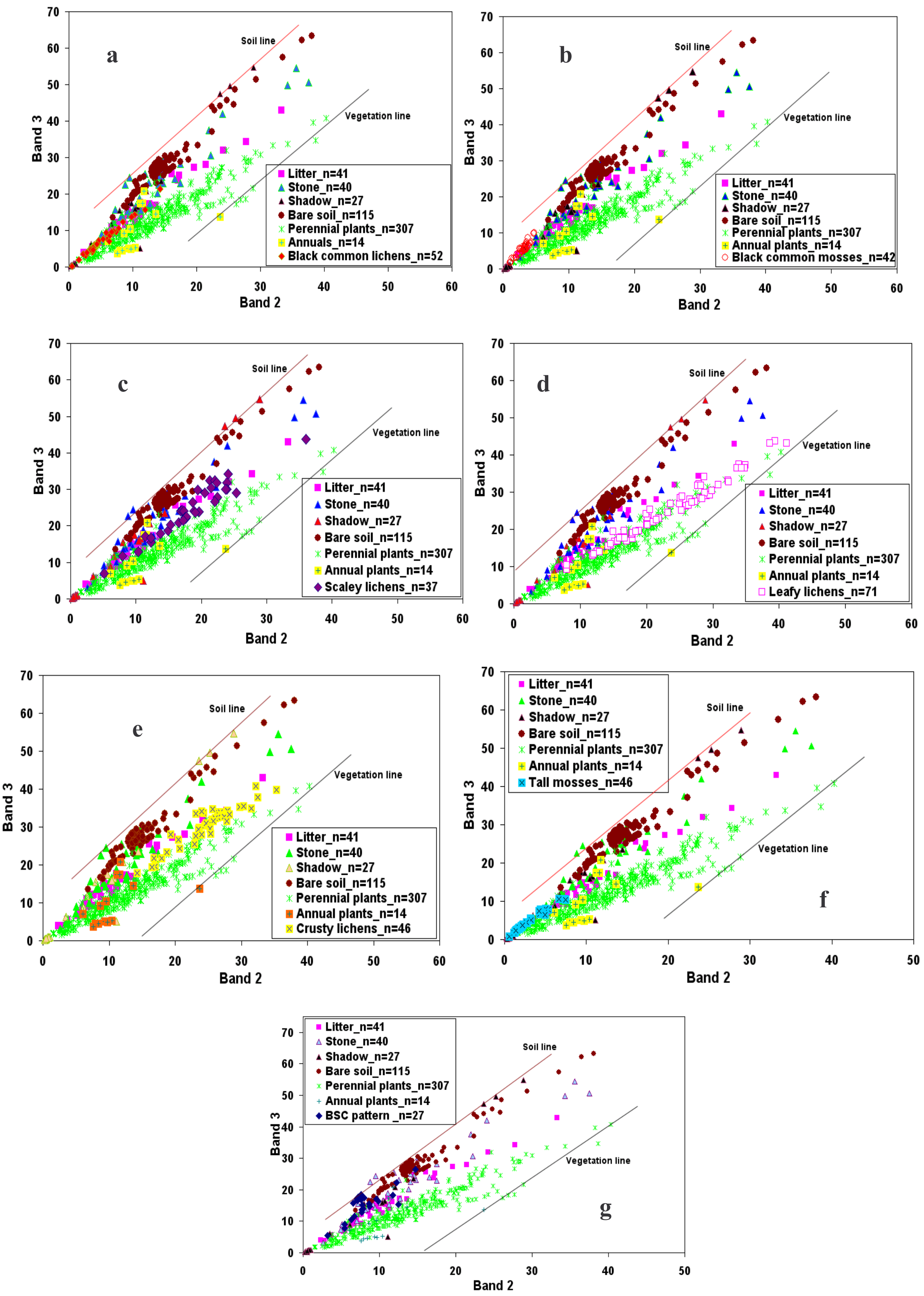

Figure 2. Distribution of ground-level reflectance data for main land covers and: a)Black Common Lichens; b) Black Common Mosses; c) Scaly Lichens; d) Leafy Lichens; e) Crusty lichens; f) Tall Mosses; and g) BSC pattern spectra in the TM data space for bands 3 *vs.* 2

Acacia spp. and *Atriplex* spp., perennial herbage and annual plants show that there was no BSC effect on the soil and vegetation lines of this method. Extensive individual BSC spectra showed that these components have no affect on the soil and vegetation lines. Moreover, although the spectra of 'BSC pattern spectra' have different brightness values and they have similar patterns to bare soil in the data space of band 3 versus band 2 of TM imagery. However, there is no affect of 'BSC pattern spectra' on the vegetation and soil lines. In soil line determination, there is the possibility of the effect of 'BSC pattern spectra'. Effect mean soil spectra and 'BSC pattern spectra' would be the same but no change in the soil line. Therefore neither individual BSC components nor 'BSC pattern spectra' affects the vegetation and soil lines, and these lines are determined by bare soil and vascular plant spectra. Thus, employing the PD54 in an area where BSC are widespread may create bias in the results of a remotely sensed method. Briefly, this index has little capability to discriminate an area with 0% of BSC cover from an area with 45% at different distances of water points. In both cases index values are defined with bare soil and vascular plants. Thus in the image interpretation by this index the value of BSC are neglected by this inefficiency. According to the vascular plant composition and distribution at MFC (Ghorbani et al. 2006), these spectral patterns can almost be expected for all paddocks. Thus, either near water with less than 1% BSC cover or 4000 m away from water points with almost 46% BSC cover (Ghorbani et al. 2006) using the PD54 could be interpreted without BSC, thus BSC will not be included and worst than that, if researchers such as Cameron and Lewis's (1996) study for ground-truthing and accuracy assessment collect BSC cover and examine a correlation matrix by including BSC cover in the image interpretation. PD54 is not a sensitive and reliable index for cover evaluation in an area in which BSC occur, if we believe the ecological role and importance of these components. Finally by applying the PD54 on the areas in which BSC are common in Australia, misclassification will increase in the results of image processing in the framework of grazing gradients with the developed models for dry and wet images (Bastin et al. 1993) with the concept of 'normal', 'inverse', 'composite' and 'no gradient' by the possibility of including or neglecting them in a given paddock.

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